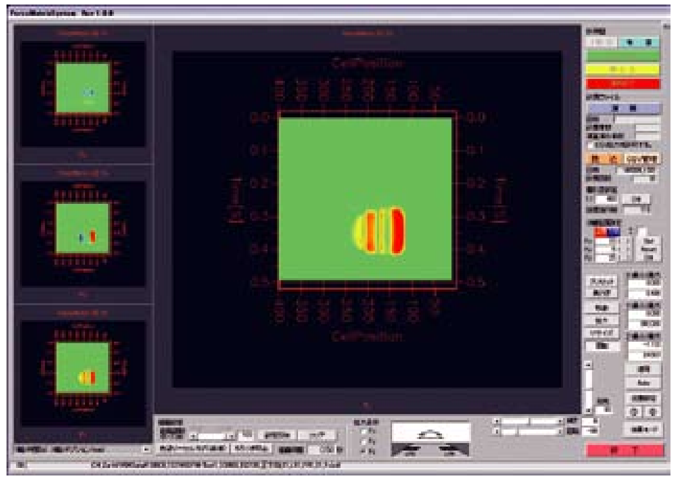
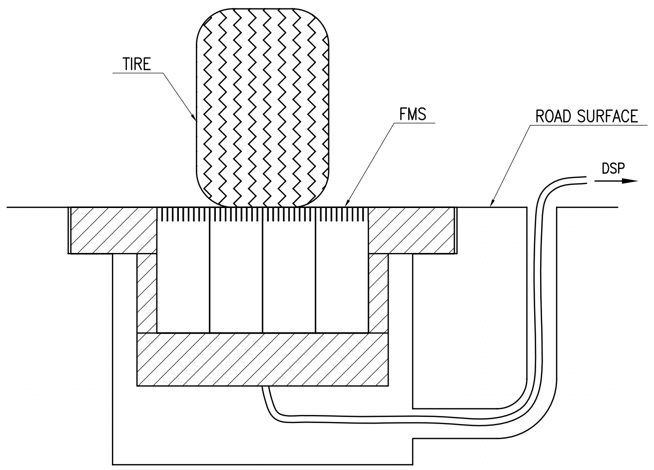
■Data Viewer (GUI example)



■Installation Example



Configured sensor units are placed into the embedded unit. The embedded unit is placed underground and sensor surface is aligned to the surface of the road. The measurement system with a DSP unit is placed aboveground.

Calibrations

1. Calibration before shipment:
Done at the factory with a calibration system. Calibrates the shared force composition matrix. All the calibration is done with deadweights.

2. Periodic calibration
Periodic calibration has to be done at the A&D factory using a calibration system. All calibration is done with deadweights and a calibration certificate can be issued.

Safety Warning!	●For proper use, read the instruction manuals carefully before use.

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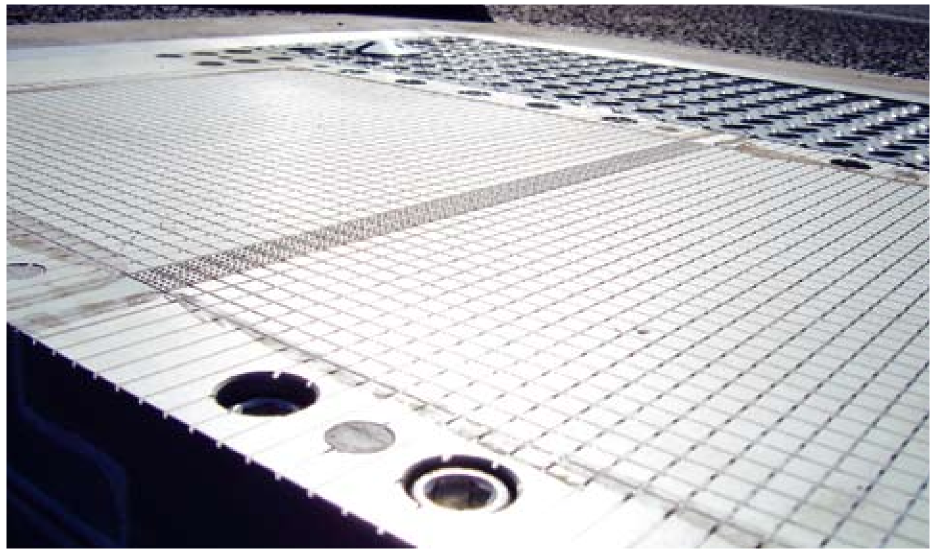
●Appearances and/or specifications subject to change for improvement without notice.
●Contents of this catalog last updated April 2011.
*FMS datasheet-ADCC-01-BP1-11401

FMS

Force Matrix Sensor



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Introduction

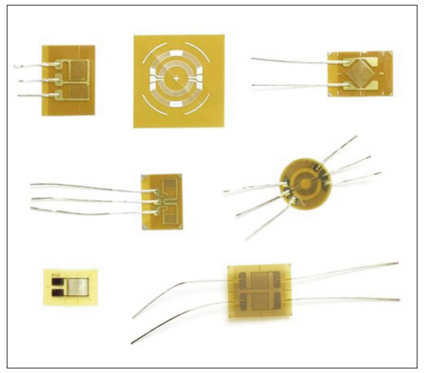
Recent trends in the tire developments have focused on energy efficient tires, comfortable driving and safe driving tires. To achieve these focus points, understanding the behavior of tires at the contact point against a real road is necessary. In order to understand how a tire behaves on a real road, many tire testing tools and measurement methods has been introduced. Measuring the rolling resistance coefficient with a drum-type tire testing machine, using flat steel belt machine to create a simulated road surface and installing a wheel force transducer on a real vehicle to measure how the tire is transferring energy to a real road are the examples. There is another approach to measurement: measure the tire behavior on the road surface side by installing an array of many small pressure sensors on the road and measure the pressure distribution when the tire runs over the pressure sensors. However, this solution provides only the radial force (Fz) information. A&D's FMS has enhanced the force distribution measurement to 3 component forces (Fx, Fy, Fz) to gain more force information for analysis of the behavior of the tire against the road, which is valuable for tire developments.

FMS (Force Matrix Sensor) is designed to be installed on a road surface to measure 3 component forces (Fx, Fy, Fz) applied from vehicle tire to the road. It is a combination of many small sensors aligned in rows or an area. The sensors are capable for measuring the 3 component forces with high speed and high accuracy.

Force Measurement and Supporting Technology

■A&D's strain gauges and spring elements

Strain gauge



A strain gauge is attached to the spring element, which deforms with applied forces and moments, and detects the strain of the spring element as electrical resistance change. Very thin metal foil is used as the material of strain gauge, which is called a foil gauge. Metal foil has excellent and robust sensing characteristics.

At A&D, in order to guarantee the quality of the sensors, strain gauges for balance products and load cell products for industry use are designed in-house for manufacturing. Therefore, optimized strain gauges for the spring element architecture can be designed in order to extract the maximum characteristics of the spring element.

For balance products, more than 1/6,000 of measurement robustness is required. Therefore, strain gauges, adhesive development, temperature compensation and analog/digital conversion technologies are also completely developed at A&D in-house.

With A&D products, the technologies cultivated for load cell and balance products are fully utilized in the FMS and 3 component force sensors, and therefore can offer highly robust and highly accurate measurement data.

High stiffness design

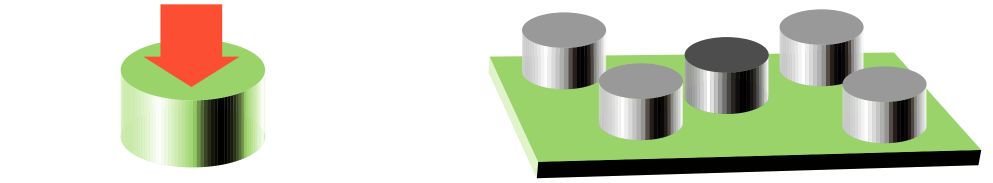
A&D's force sensors use shear beams, which can minimize deflection against the applied force. Therefore, the sensor is designed to be as stiff as possible. Because of the small deflection, the senor uses the elastic characteristics of the material to a significant advantage in achieving ideal linearity, hysterisis and repeatability. Also, the stiff design has the advantage of a high mechanical eigen frequency and a long lifetime.

■Balance technology

Moment cancellation and shared force composition technology

In balance products, there is a measurement plate to support the item under the measurement. The balance is tuned to show exactly the same measurement result regardless of where the item is placed on the plate. This requires cancellation of the moments.

For a small-sized balance, the cancellation of the moments is achieved by modifying the shape of the load cell. On the other hand, for a large-sized balance, 4 to 8 load cells are used and a balance computer calculates the shared forces of the load cells in order to cancel out the moments.



■Modeling technology

A model-based calculation method is applied to cancel out the cross-talk effect from the measurement, and calculate the component forces accurately from the detected shared forces. Cancellation of cross-talk effects is done with model-based calculation, which includes complex matrix calculations such as a shared force composition matrix. The FMS is calibrated by defining the parameter values of these matrixes.

This new type of calibration system enables modeling of the error and produces a calibrated shared force composition matrix. The calibration system uses more than 1/50,000 class deadweight and applies 3-component force load to the sensor. Therefore, the calibration system is able to analyze the relationship of loaded forces and shared forces and thus can create a sensor error matrix model. The inverted sensor error matrix model is applied to the shared force composition matrix and creates a calibrated shared force composition matrix.

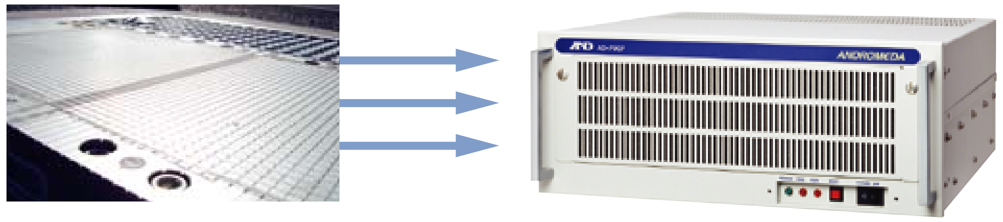
DSP technology

Realtime digital signal processing (DSP) platform

The Realtime DSP platform was developed for hardware in the loop systems (HILS) and rapid prototype controllers (RPT), which are widely used in vehicle powertrain development. The DSP platform has the high computing ability necessary to process large simulation models in realtime. This technology is applied to A&D's force measurement sensors.

Conventional analog-sensor amplifiers cannot apply complicated calculation processes. The main concept difference of A&D's component force sensors is that measured analog signals are converted to digital signals and the signals are processed digitally by the DSP system. With this method, complicated model calculation, such as the shared force composition matrix, is applied for component force determination. Because of this DSP technology, highly sophisticated data calculation to achieve highly accurate and robust measurement is possible. This is the reason the FMS is called a model-based sensor (MBS).

DSP System (AD7907)



Digital Calculation Processing

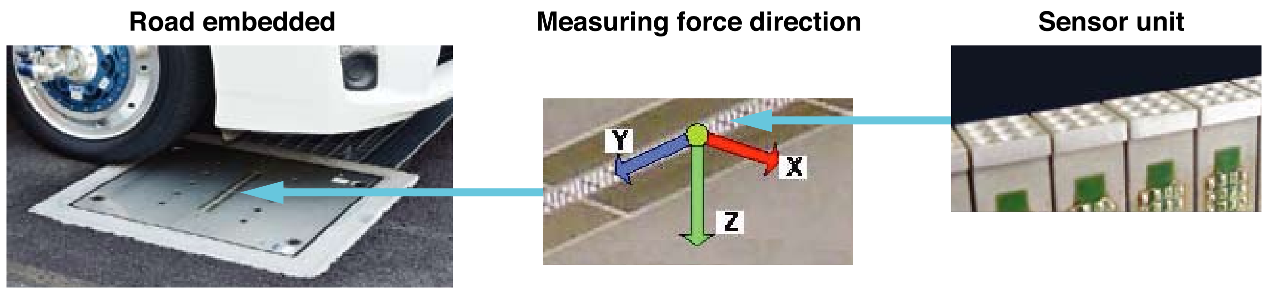
Analog to digital conversion technology

Since the force-sensing signal is directly converted to a digital signal, the electronic circuitry of sensor unit can be miniaturized. This prevents unnecessary electronic noise from entering into the measurement. Still, the raw detection signal from the strain gauge is small (mV order). In order to achieve high resolution, A&D's A/D converter is capable of nV order conversion.

FMS

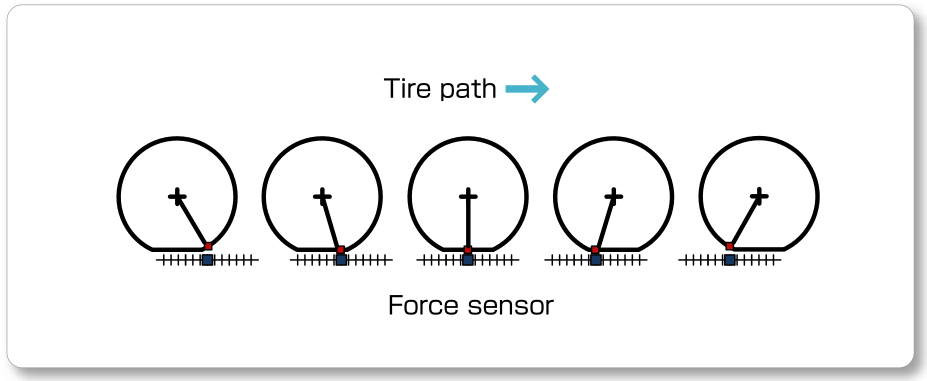
FMS (Force Matrix Sensor) is designed to be installed on a road surface to measure 3 component forces (Fx, Fy, Fz) applied by vehicle tire to the road. It is a combination of many small sensors aligned in rows or an area. The sensors are capable for measuring 3 component forces with high speed and high accuracy. Small 8 mm × 8 mm sensors located in rows measure the reaction force of vehicle tire against the sensors with high accuracy. By combining the sensor signals, a force distribution of the tire against the road can be analyzed.

The measuring system has a 20 ksps (kilo sampling per second) data acquisition capability and measures all the sensor signals simultaneously. This sampling speed is fast enough to measure force distribution up to a vehicle velocity of 300 km/h. The size of sensors (8 mm x 8 mm) makes it possible to detect space between the tread patterns of the tire. (The sensor itself is 7.5 mm x 7.5 mm. A 0.5 mm gap is necessary between sensors.) The vehicle runs over the line of arrayed sensors as shown in the picture below.

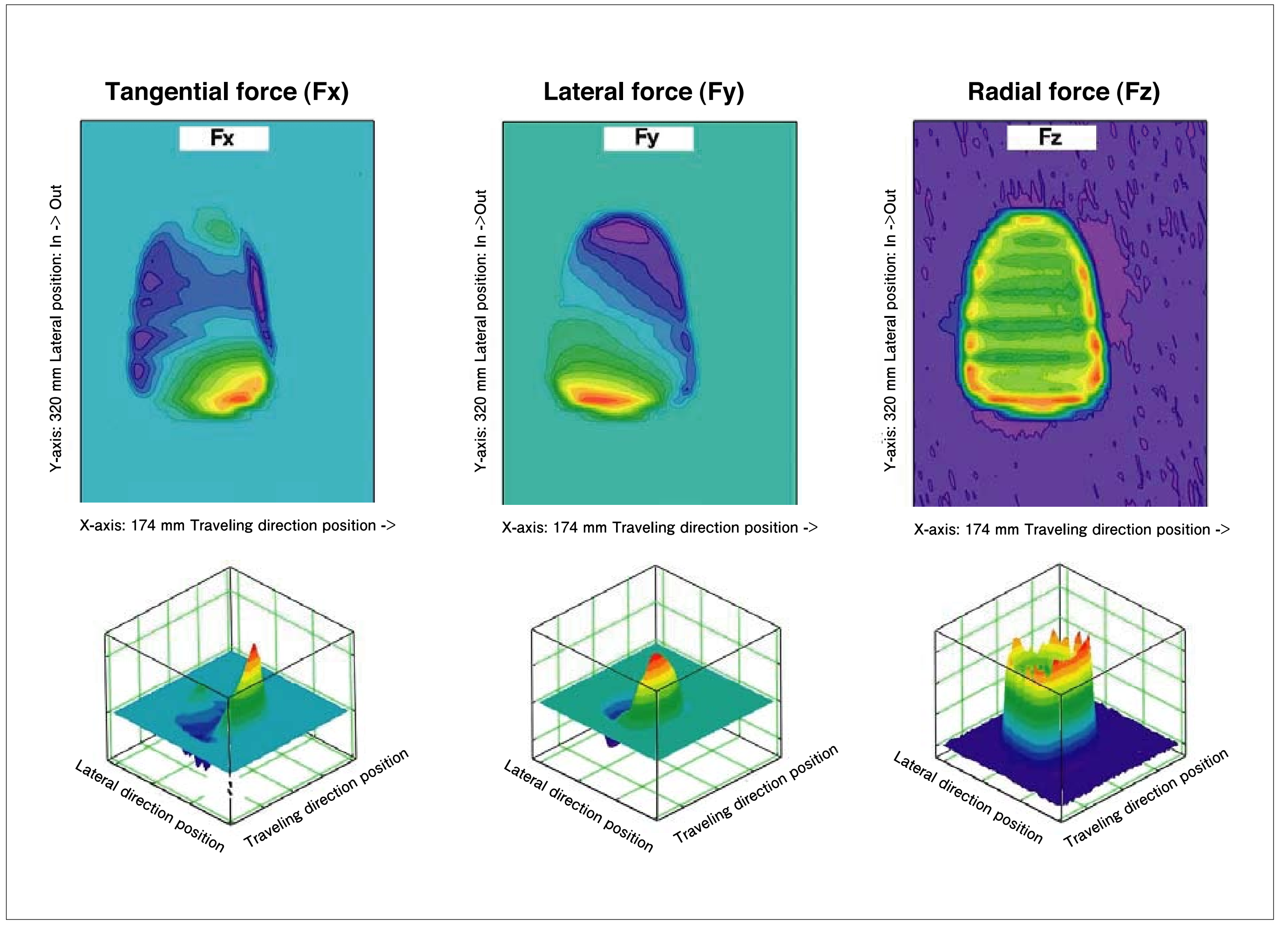


The sensors observe the time-based force change at the contact point of the tire and the sensors, as shown in figure below.

The acquired data is post-processed using application software that can analyze the force distribution of the 3 component forces and draw a contour figure and time-based 3-D graph to provide visual understanding.



Component force contour figure

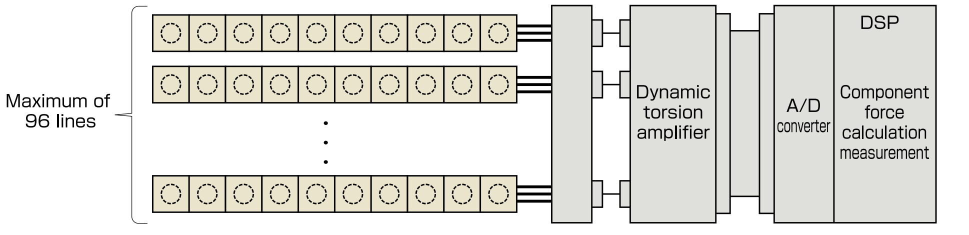


FMS uses A&D's unique force measuring concept of MBS (Model Based Sensor) and measures 3 component forces (Fx, Fy, Fz). This has two major advantages. One is the measurement has high accuracy (±1N) and the other is simultaneous measurement, because all data from all the configured sensors have the same time stamp. These two major features offer realistic analytical data of how the tire is applying the force to the road surface for the study of tire behavior on a real road.

FMS System Hardware Configuration

■FMS Configuration

FMS Configuration



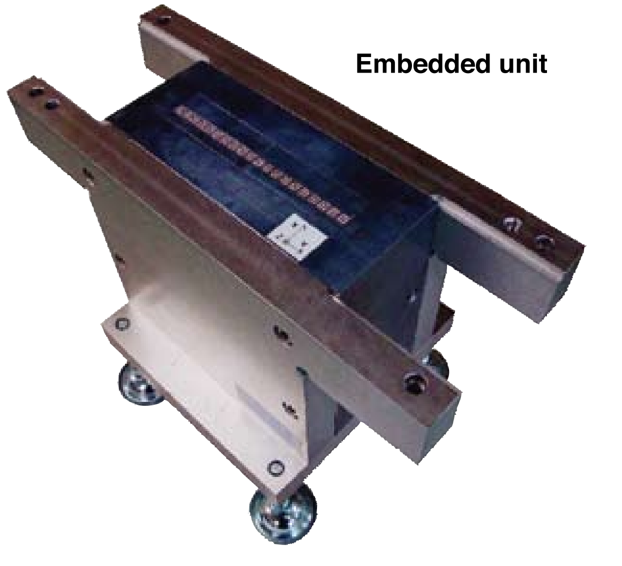
FMS Sensor Layout (Example)

Sensor unit

Ten 7.5 mm × 7.5 mm sensors are placed in a row with a 0.5 mm gap between the sensors. This is the basic unit for FMS. Up to 96 units (960 sensors) can be configured as one measuring system. Also, the sensor units can be aligned in a row or column and can be configured as a sensor group as user prefers. Thanks to this feature, the sensor unit layout has high degree of freedom. It can correspond to short and wide width tires, and can also be configured to meet surface measurement requirements.

Sensor Unit

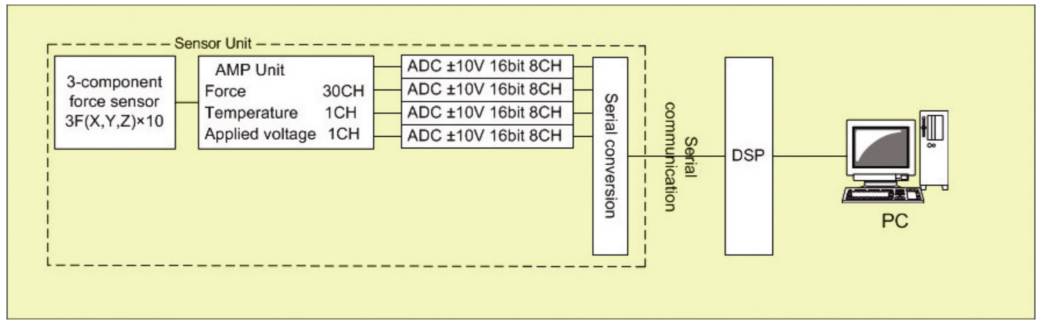
Embedded unit



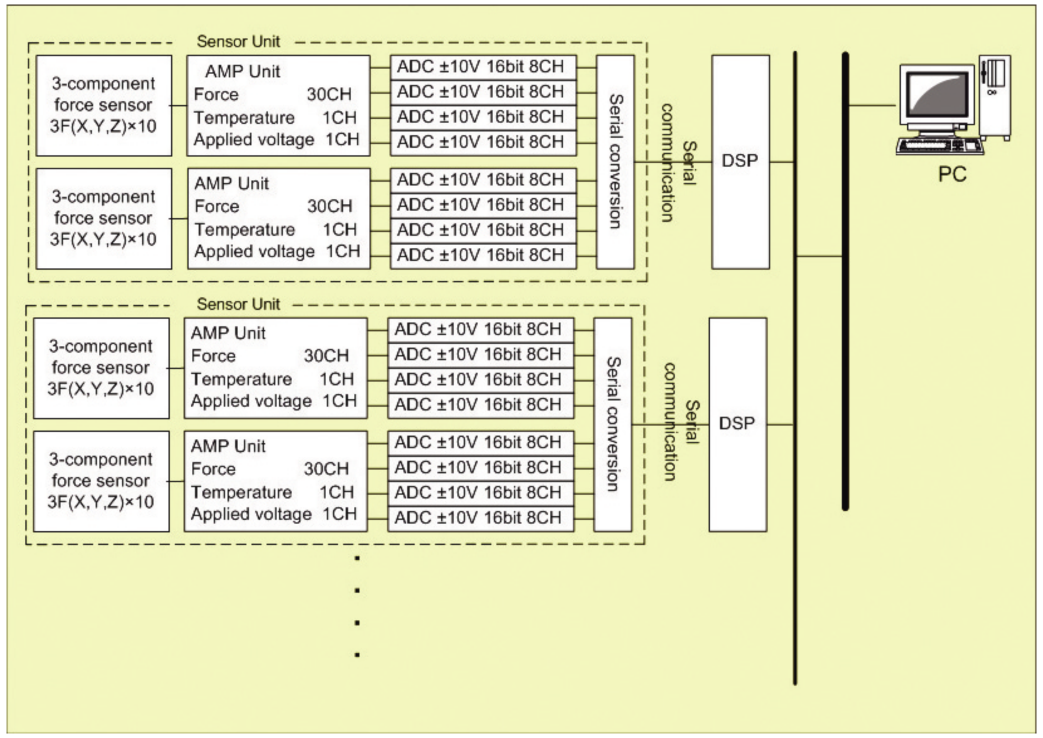
The configured sensors are mounted on the embedded unit and placed underground with the surface of embedded unit is aligned with the road surface. The vehicle runs over the sensor and the reaction force (3 component forces) from the tire is measured.

System Hardware configuration

Hardware configuration 1 Unit configuration (reference)



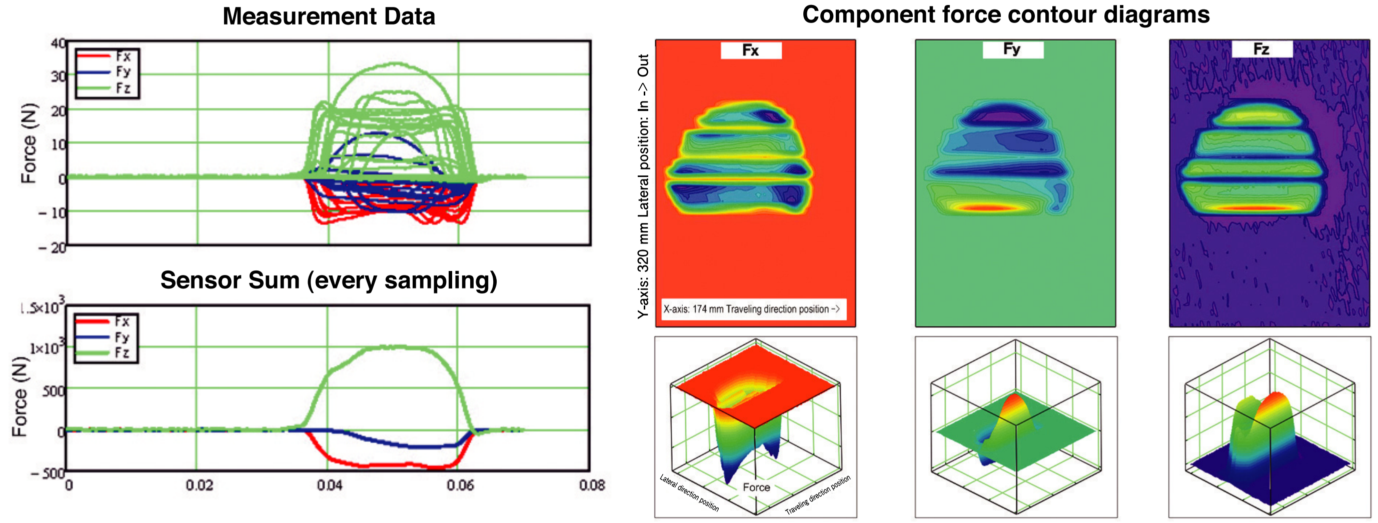
Hardware configuration Multi Unit configuration (reference)



Each sensor has 3 channels for force gauge output. The sensor unit has 1 channel for temperature output, and is equipped with an amplifier. The signals are converted to a digital signal at the sensor unit with high-speed A/D (20 kHz) and all the signals have the same time stamp. This minimizes the electrical noise coming into the measurements. Digitalized sensor data is transferred via high-speed serial interface to the DSP system and composes the 3 component forces with model-based matrix calculation.
The 3 component force data for each sensor processed at the DSP system is transferred to Operation PC. The application SW at the Operation PC post-processes the measured data and provides user-analyzed data with various expressions. By using the high-speed DSP system, the measurement system is able to handle 960 sensors for simultaneous measurement.

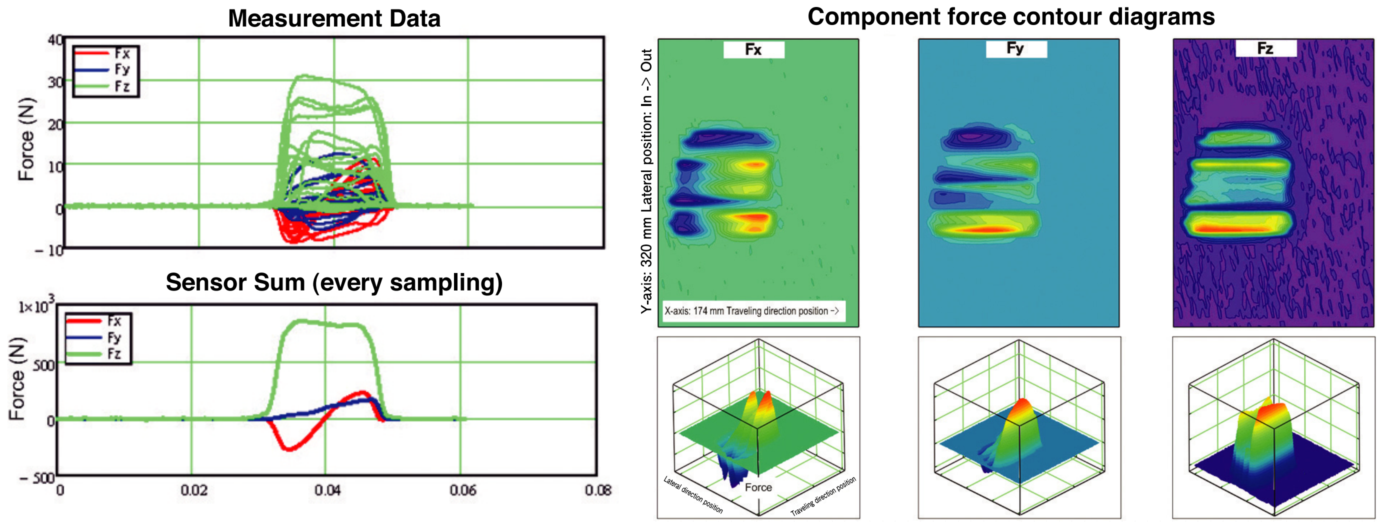
Acquired data example

■Acceleration ON running Passenger seat: 60 kg Rear seat: 120 kg Front wheel



Item	Value	Unit
Velocity	17.81	km/h
Fx Tangential force	-1354	N
Fy Lateral force	-440	N
Fz Radial force	2812	N

■Acceleration ON running Passenger seat: 60 kg Rear seat: 120 kg Rear wheel



Item	Value	Unit
Velocity	20.50	km/h
Fx Tangential force	-27	N
Fy Lateral force	239	N
Fz Radial force	2022	N

Sensor Specification

Item		Specification	Note
Sensor size		7.5 mm x 7.5 mm	There is a 0.5 mm gap between the sensors
Input force range	Fz	100N per sensor 177N/cm^2	177N/cm^2
	Fx	50N per sensor	88N/cm^2
	Fy	50N per sensor	88N/cm^2
Total accuracy		≦ ±1N (Fz: 1%, Fx:2%, Fy:2%)	
Overload capacity		150% per sensor	
Measuring speed at vehicle speed		0-300 km/h	The sensor can detect the tire force signal up to 300 km/h
Sensor response time		5 kHz	This is the eigen frequency of the sensor.
Sampling rate		20 ksps (kilo sampling per second)	All channel simultaneous sampling
Sensor unit	Sensor block	10 sensor array	
	Protection	No use under wet conditions	
	Operating temperature	-20 to 80 °C	
Embedded unit			Customized for the customer sensor configuration

Measurement Specification

Item	Specification	Note
●Measurement / calculation		
3 component force calculation	Digital model calculation	
Measurement system response time	10 kHz	Total response time is limited to eigen frequency of the sensor (5 kHz)
Maximum configurable sensor units	96 units (960 sensors)	
Measurement items	X-force Fx (N), Y-force Fy (N), Z-force Fz (N), time stamp	
Measurement trigger	Selectable from phototube switch trigger and manual trigger	
●Output signal		
Output signal interface	Fx(N), Fy(N), Fz(N), digitally stored as binary file with time stamp	
●DSP system		
Name	AD7907	
Size	435 mm(W) x 177 mm(H) x 450 mm(D)	
Weight	20 kg	
Power supply	AC 115-230 V	
Operational temperature range	5 to 40 ℃	
Operation humidity range	5 to 90% RH	No condensation
●Operation PC	OS: Windows XP and later (English and Japanese versions)	
Data storage	Operation PC specified holder	
Saved data format	Dedicated binary	Possible to convert to CSV using data viewer
Measurement command	Start: Software GUI, Stop: Software GUI	Phototube SW trigger can be selected
●Data viewer (PC Software)	PC Application Software and post processing tool	
Display	Display Display saved data files as ●Specified time-line graph ●Data integrated time-line graph ●Contour figure ●3D time-line graph	
Export	Possible to export as a CSV file	